Low / No carbon fuels - impact on particulate emissions of HD engines

14th VERT Forum, T. Philipp

VERT Association

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Liebherr Machines Bulle SA

Agenda

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2 Use of low or no carbon fuels
3 Impact of different fuels
4 Conclusion and outlook

01
Introduction

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Factsheet: Liebherr Machines Bulle SA

1978

Foundation

Components Division:

Liebherr-Component Technologies AG, Bulle (Switzerland)

A specialist in heavy duty combustion engines and hydraulics

Product segments

Hydraulic pumps and motors – industry / aviation

Combustion engines

Fuel injection system development

1 520

Employees

500

Mio. CHF turnover

Total area: 188 100 m²

Built-up area : 83 696 m²

Impact of Liebherr applications on global greenhouse gas emissions

In general, construction machinery plays 2 important roles for the global transformation to a decarbonised economy

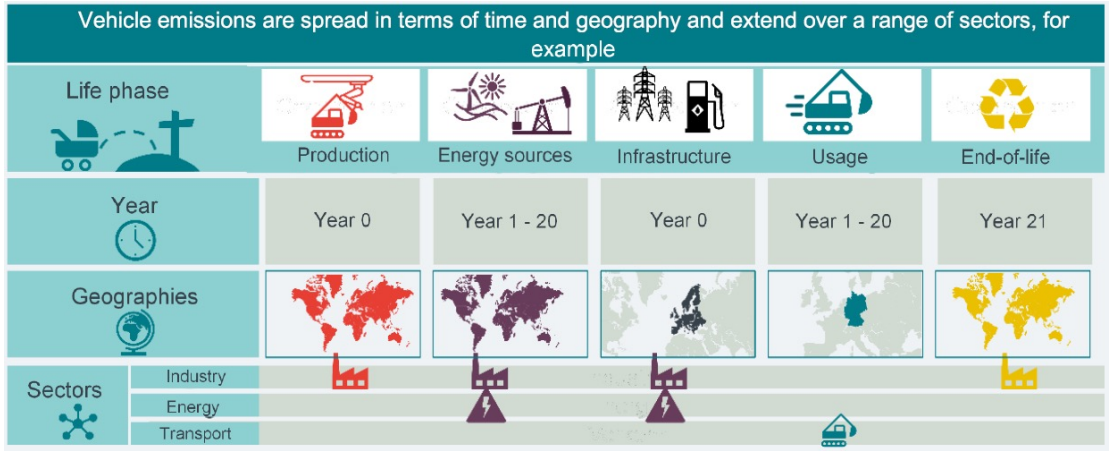
- Liebherr applications and components are enabling the supply with raw material and the expansion of the infrastructure for the energy transition

- Today, many applications are based on a fossil fuel-based powertrain, high power request and continuous operation, which makes them remarkable CO_2-Emitters

Impact analysis for Liebherr applications

Liebherr started a program to identify the optimum powertrain technology regarding greenhouse gas emissions, by using a holistic life cycle analysis (LCA) approach, including:

- Production of the application & Energy sources
- Infrastructure for the energy supply
- Usage of the application
- Scrapping or recycling of raw materials



Looking only on a single phase of the whole lifecycle can lead to a conclusion which finally will lead to higher overall emissions, only transferred to a different phase

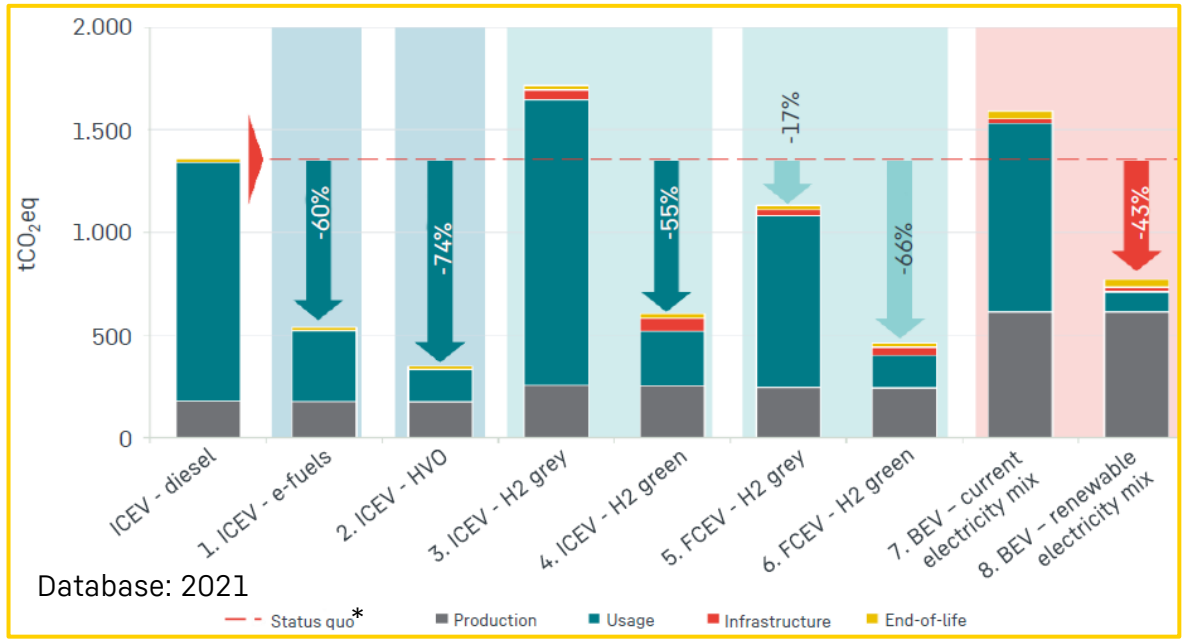
Results of the lifecycle analysis (*)

The biggest part of the CO_2-equivalents is produced during **operation** of the machine

Reduction of greenhouse gas emissions is one additional requirement for future powertrain developments

Overall results are depending on the **usage of the application**

No **standardised solution** for all applications



ICEV: internal combustion equipped vehicle
FCEV: fuell cell equipped vehicle
BEV: battery electric vehicle
*Results based on current state-of-the Art

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02
Use of low or no carbon fuels

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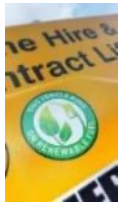
Fuels/Technologies in focus at Liebherr

Liebherr Machines Bulle SA as manufacturer of internal combustion engines for construction and agricultural applications is looking on different pathways to lower greenhouse gas emissions

- **GTL/HVO:** based on EN15940
- **Dual Fuel:** Mix of Diesel fuel and H_2
- **Hydrogen:** no CO_2 by combustion
- **Ammonia:** no CO_2 by combustion – partner in Campfire project



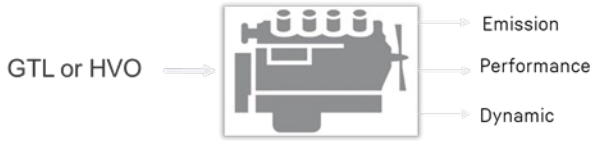
Motivation – GTL / HVO (EN15940)

Can be used as Drop-in fuel with existing engine and aftertreatment technologies

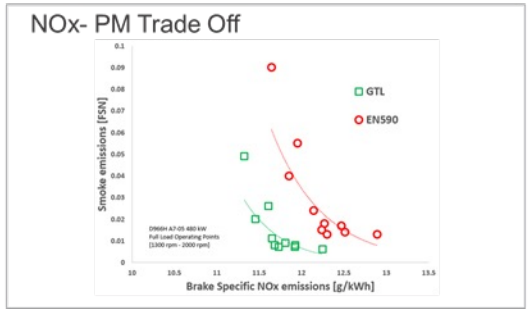
Existing infrastructure can be used

Produced from renewable raw materials

Paraffinic Fuels EN15940 (HVO, GTL)



Engine investigation in test bench



Fuel analysis with LMB Engines (HVO)

- Investigation with synthetic fuel "HVO" performed with LMB engines
- CO2 emission reduction in "Tank to wheel" scenario is ~ 4 %
- In Well to wheel scenario a potential of 80% - 90 % of CO2 emission reduction is expected
- Volumetric fuel consumption is increased with approximatively 4 %

Liebherr OEMs uses HVO as "First fill" for its applications

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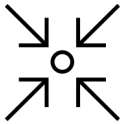
Why Dual-Fuel Technology ?

Emergency operation with diesel mode is always possible

Ensuring the second life of vehicles in all markets without H_2 infrastructure

Flexibility in vehicle operation (vehicle can operate in two modes)

Ensuring the low emission vehicle “LEV: 50% CO_2 emissions ~ 350 g/kWh” norms



Tank volume for 100 % hydrogen operation is very challenging for integration (Limitation of H_2 operation in dedicated area recommended, e.g. Crane mode in cities)

Additional Engine performance (dynamic operation) using diesel boost is possible

Motivation Hydrogen

Carbon neutral technology thanks to low CO_2 emissions

Very low NOx emissions thanks to a special design of the combustion chamber, optimization of air system and dedicated EATS

Comparable interfaces (thermal & mechanical) to diesel engine

Good **engine efficiency** all over the engine operating conditions

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Impact of different fuels

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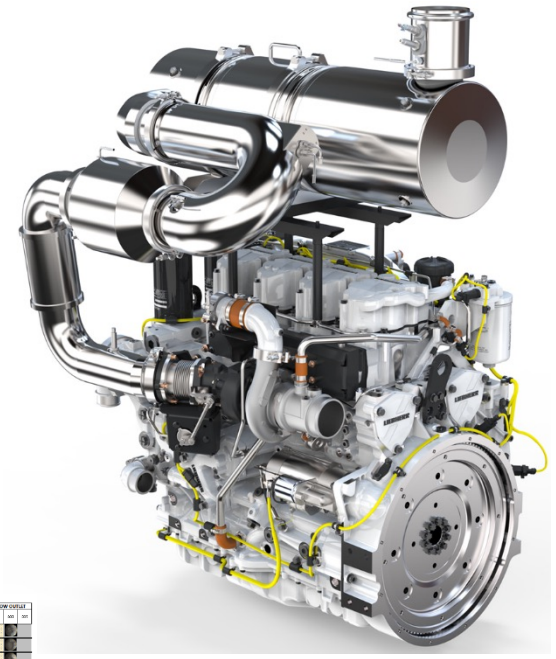
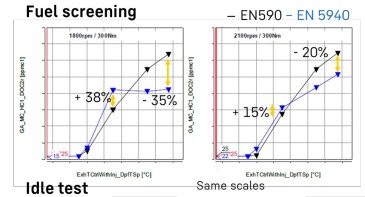
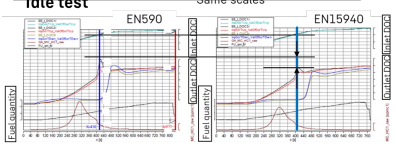
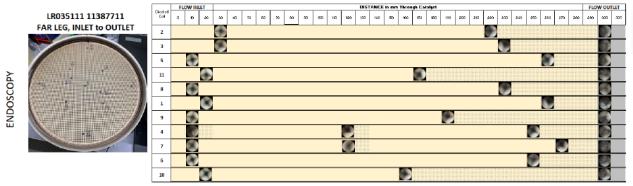
GTL / HVO – Investigation @ Liebherr

HVO ready









EN15940 validation performed.

The analysis focussed on:

- DOC behaviour
- 1'000hrs endurance test

DOC behaviour:

- Identified different behaviour (lower peak exotherm temperature, HC slip) without functional impact on the regeneration capability

1'000hrs endurance test:

- Ash load rate ~30% lower than expected
- lower soot load

- **No impact on the EATS performance was found by using EN15940 fuels**
- **Stage V SCRFilter fulfil requirement for soot filtration**
- **Stage V engines certified for use with EN15940 fuels**

Hydrogen – Situation

Currently, no **dedicated emission regulation for H_2 engines**: missing method for calculating emissions with zero carbon fuels. In EU, expected amendment of ECE R.96 regulation end of 2024

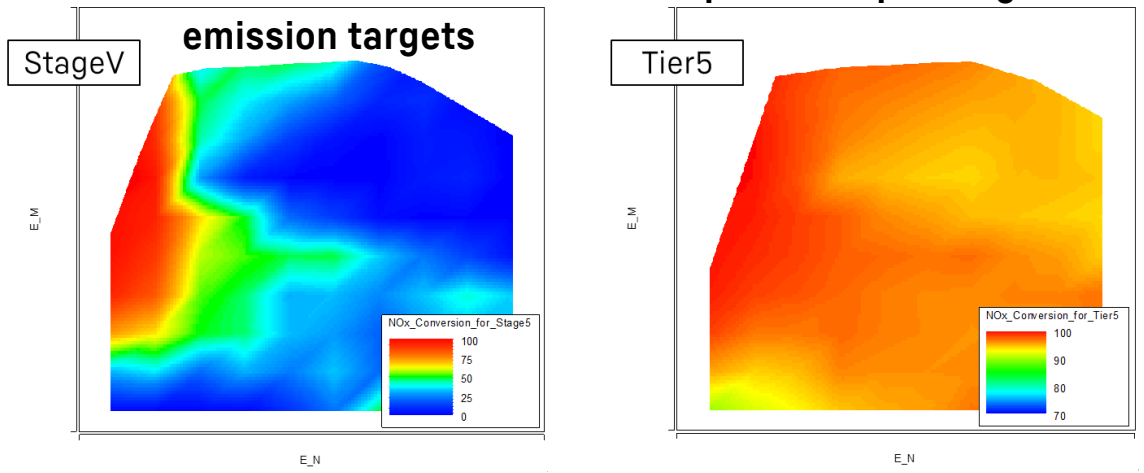
With today's engine only technologies, the achievement of Stage V emission legislation is not assured

By using an EATS (e.g. Stage V SCRFilter system) the limits of Stage V can be reached.

To reach further emission legislation, improvements on the EATS are expected.

	Stage V / T4f	Tier 5 proposal
NO_x	0.4 g/kWh	0.04 g/kWh
N_2O	n/a	0.15 g/kWh capping
THC	0.019 g/kWh	0.019 g/kWh
PM	0.015 g/kWh	0.005 g/kWh
PN	$1x10^{12}$ (PN23) EU	$1x10^{12}$ (PN23) $6x10^{11}$ (PN10) ?
Validation	NTE	NTE? Percentiles/low load cycles?

NOx conversion rates to be expected depending on emission targets



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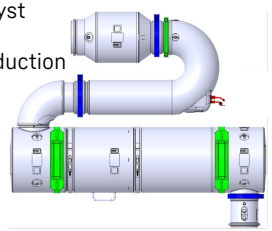
Hydrogen – theoretical analysis of current system vs. PoC

DOC: Diesel Oxidation catalyst
SCRoF: SCR on Filter
SCR: Selective Catalytic Reduction
ASC: Ammonia Slip catalyst



Using the standard Stage V EATS in the H_2 "environment", a careful assessment is required to anticipate / highlight potential risks and to define the test targets.

DOC Functions	Useful for H_2 eng.? Theoretical analysis	Proof-of-concept (PoC)
Late-post rgn and thermal management (HC oxidation) NO oxidation to NO_2 for soot passive rgn in SCRoF H2 oxidation	No No, NO_2 will be used for SCR reaction Yes	High DOC-performance confirmed for H_2 oxidation – sizing potential

ASC Functions	Useful for H_2 eng.? Theoretical analysis	Proof-of-concept (PoC)
NH_3-slip oxydation H_2 Oxydation	Yes Yes	H_2: Positive impact, not at same level as DOC

SCRoF functions	Useful for H_2 eng.? Theoretical analysis	Proof-of-concept (PoC)
Soot filtration and passive rgn Ash filtration NO_x conversion Serviceable – exchangeable filter	No Yes Yes No	Positive impact on particulate filtration, raw emissions already below Stage V level

SCR Functions	Useful for H_2 eng.? Theoretical analysis	Proof-of-concept (PoC)
NO_x conversion H_2 Oxydation (limited)	Yes Yes (tbc)	NO_x conversion rates on good level, sizing and dosing strategy optimisation will further improve the result H_2 oxidation needs further investigation

Achievement of the Stage V emission targets is feasible with the existing system layout. Impact on durability is under evaluation. To meet more stringent limits, further improvements are required.

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04
Conclusion and outlook

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Conclusion and Outlook

The internal combustion engine shows further emission reduction potential by exchanging standard fuels by alternative fuels (EN15940, H_2)

- focussing on partial analysis can lead to a wrong interpretation of the best technical solution
- The use profile of the application needs to be considered to choose the best powertrain concept
- Dual fuel applications can be considered as transfer technologies with a faster market availability

A positive impact on particulate matter emission is already found with EN15940 fuels, and can be further reduced using no carbon fuels

- Particulate emissions are not only related to the carbon content in the fuel, but are also impacted by other sources (oil additives, engine wear, DEF dosing)
- The use of a particulate filters shows a positive impact, even on “No carbon” fuels

Uncertainty about applicable limits and homologation constraints the introduction of emission reduction technologies

- In addition to the emission legislation, EU threshold for CO_2 neutrality under discussion

Thank you.

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